The Magic of Radio Wave Propagation—Part 1

There is no sleight of hand in this magic, just science! A science of the sun, the Earth, and the Earth's atmosphere...a science that is basic to radio, and the better you understand it, the better your chances of using it to improve your ability to communicate.

By Lew Ozimek, N2OZ*
(lozimekn2oz@erols.com)

Radio communication. We all know how it works, right? You merely talk into a microphone or press a CW key connected to a transmitter and your voice or Morse code is reproduced in a speaker or earphones at a distant receiver. But what happened between the two stations? There is no wire interconnection and the distance of separation is too great for sound waves to have traveled directly between the two. But somehow, a form of audio or Morse code is transferred from one location to another. How does it happen?

Starting in the 1800s

What actually occurs may be a mystery to many of us, but it was explained as far back as the late 1800s, when Heinrich Hertz created electromagnetic waves and demonstrated that radio waves could be transmitted and received over relatively short distances. A few years later, Guglielmo Marconi, recognizing the potential for long-range contacts, produced the first practical wireless telegraph system. Capabilities increased quite rapidly and, in 1901, the first Transatlantic message was sent from England to Newfoundland. A significant advance had occurred in the "art" of radio communication, but no one was yet able to explain the "science," other than the fact that radio waves moved from one location to another, which was not much of an explanation.

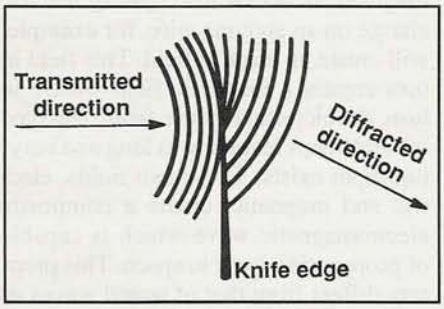

Figure 1. Long-distance radio communication depends on the deflection of signals that would otherwise be radiated into space. One of the many forms and types of deflection that affects radio signals, knife-edge diffraction, is shown here and explained in the text.

The first major advance in solving the riddle of "why and how" became possible after Arthur Kennelly in the U.S. and Oliver Heaviside in Great Britain simultaneously theorized, in 1902, that the Earth's upper atmosphere was made up of electrically conducting "regions." They did not, however, connect this atmosphere to radio wave propagation.

The existence of the Kennelly/Heaviside "region" was proven 25 years later when Sir Edward Appelton of Great Britain measured the reflected angles of radio waves transmitted toward space. The results demonstrated not only that such a region existed, about 100 miles above the Earth's surface, but also that it was capable of reflecting radio signals.

That same year, American physicists Gregory Briet and Merle Tuve developed techniques to accurately measure the height of the reflective layers in the ionosphere by transmitting short bursts of radio energy straight up. The tests showed that reflections were frequency-dependent and that, as the frequency of radio waves increased, a point was ultimately reached where reflections stopped. Extensive tests using their technique proved that this "highest reflected frequency at vertical incidence" (now known as the *critical frequency*) changed from day to day, from month to month, and from one location to another.

In 1927, during a total eclipse of the sun, a sharp decrease in *critical frequency* was observed. This eclipse and its effect on the *critical frequency* guided observers to the conclusion that solar ultraviolet radiation was primarily responsible for the generation of ionized layers in the atmosphere and that the extent of ionization and the height of the layers determined the *critical frequency* by creating different "reflective charac-

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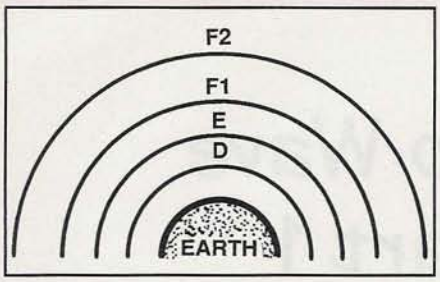

Figure 2. The ionosphere, which is responsible for most long-distance propagation, contains four layers that affect radio signals: D, E, F_1 *and* F_2. *The role of each layer is explained in the text.*

teristics." It was also determined that the intensity of ultraviolet radiation was directly tied to storms, called *sunspots,* occurring on the surface of the sun. Considering the early stages in the development of such ideas, that conclusion was amazingly accurate.

The Importance of Sunspots

The existence of sunspots was not a new concept, but understanding the effect they had was new. Sunspots were first observed by the Chinese many years before Christ, but nothing was known about them except that they existed. The first record of sunspot activity was made in 1611, one year after Galileo invented the telescope. Sporadic records of sunspot cycles, or solar storms as they were correctly characterized, were made in subsequent years. Formal sunspot measurements and records were started in 1749 and have been maintained continuously until this day. This 250-year record proved that solar activity increased and decreased cyclically over a period of about 11 years. During any 11-year period, the number of sunspots counted would go from a maximum to a minimum and then back to a maximum.

Today, we are in the early stages of sunspot cycle 23, which began earlier this year, when measurements disclosed that sunspot activity had started to increase—a long stretch from cycle one, which started about 1755. Since radio communication improves proportionally with the sun's activity, we are on the threshold of major radio propagation improvement which will probably reach a peak by the year 2004. That being the case, it surely behooves us to determine what the increased sunspot activity may mean to our ability to communicate and how we can take advantage of any upcoming opportunities.

What Are Radio Waves?

Those early scientists certainly recognized the existence of radio waves and demonstrated how they could be used. But what *are* radio waves? We know a lot more about them today than we did at the beginning of this century. We now know that there is a large "family" of electromagnetic waves, including gamma rays, cosmic rays, X-rays, light rays (including ultra-violet, visible, and infrared) and radio waves. Each has its own range of frequencies (or wavelengths) with radio waves being the lowest in frequency (longest wavelength). Radio encompasses that portion of the electromagnetic spectrum containing frequencies of 10 kHz through 300 GHz (wavelengths of 30,000 kilometers to 1 millimeter).

All electromagnetic waves are generated by the interaction of electric and magnetic fields. An oscillating electric charge on an antenna wire, for example, will create an electric field. This field in turn creates a magnetic field which, in turn, develops an electric field. The type of field keeps reversing as long as a varying input exists. These two fields, electric and magnetic, create a composite electromagnetic wave which is capable of propagating itself in space. This property differs from that of sound waves or ocean waves, which need a medium such as air or water to permit propagation. Thus, radio waves are capable of traveling through a vacuum (such as space) as well as through a solid (such as wire). They travel in a vacuum at a constant speed of 186,400 miles/sec (300,000 km/sec)—the speed of light—and their speed decreases slightly when traveling through a solid such as a wire. (These are very dry facts, to be sure, which may not be helpful to an amateur only interested in improving communication. What's important though, is the way that radio waves move and what happens to them on the way.)

Obstacles and Opportunities

Radio waves weaken as they move away from a signal source in air, or even in the near vacuum of cosmic space, because of *free-space attenuation,* an action through which radio energy is dispersed over a larger and larger area with increasing distance. It's much like the beam of a flashlight, which covers a broader area, but more weakly, the farther away it hits. Free-space attenuation is the major factor governing signal strength.

Radio waves moving through any medium other than a vacuum also lose energy due to *absorption.* Wave movement is not very efficient and as a result, heat is developed, which stays in the propagating medium and is *absorbed.* The amount of energy lost depends upon the frequency of the wave and the characteristics of the medium.

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Radio waves normally travel in straight lines until they are *deflected.* Anytime a deflection takes place, energy is lost and the wave changes direction. It is this change of direction, however, that makes long-distance communication possible. Waves traveling from one medium to another, such as through different layers of the atmosphere, are bent or *refracted,* a form of deflection. This effect can be observed when a pencil is dipped into a glass of water and, when viewed from the side, looks bent. The apparent bending is a result of wave *refraction.*

Radio waves traveling over solid objects with sharp edges are bent towards the edge or *diffracted,* another form of deflection, known as *knife-edge diffraction* (see Figure 1). In addition, when radio waves meet randomly arranged objects, such as masses of electrons, ionized particles, water drops, or snow flakes, their direction of travel is changed, or *deflected,* by a phenomenon known as *scattering.*

At frequencies above 30 MHz, radio waves are *reflected* (another form of deflection) when they strike large stationary objects, such as buildings, bridges or mountains. After the waves strike an object, they are deflected and move away from the object at an angle.

On the lower frequency bands, especially 80 and 160 meters, a special form

of *diffraction* creates *ground waves*, which allows the signal to travel over distances beyond 120 miles. This occurs because the curvature of the Earth acts like a rounded knife edge at these long wavelengths, *diffracting* the wave down towards the Earth's surface and allowing the signal to follow its curvature.

What has all of this told us so far? Radio waves are only one of a number of different types of electromagnetic phenomena. They need no medium for propagation (a major difference from sound and ocean waves), and they are just as happy traveling through a vacuum as through a wire or other form of metal. In space, they lose strength as they move away from the generating source because of *free-space attenuation*. Waves traveling through a medium other than a vacuum lose energy by the absorption of the heat generated by the process used to move within the medium, another form of strength loss. They like to travel in straight lines, but are relatively easily deflected by *refraction, diffraction, reflection,* or *scattering*. Each such deflection also results in a loss of energy. Despite the dispersion of the radio signal and all of the obstacles which rob it of energy and reduce its power, somehow the radio wave persists and, more likely than not, achieves its objective of reaching a distant station.

We also know that one form of propagation is the *ground wave*, in which propagation improves as frequency decreases, and where the distances covered go from a few miles to more than 100 miles. AM broadcast stations use this mode to reach listeners, but it is of limited value to amateurs, except perhaps at 1.8 MHz.

Look! Up in the Sky!

The other major form of propagation is the *sky wave*. This phenomenon occurs because of the tendency of radio waves to travel in straight lines and the fact that they can be easily deflected. If a radio wave travels in a straight line away from an antenna on Earth, what can it encounter which will deflect it? The only straight line path it can follow is into the area surrounding the Earth, that is, into the gaseous mass called the *atmosphere*. The atmosphere extends out several hundred miles from the Earth's surface and is divided into several layers.

The portion of the atmosphere that starts at the surface and goes up to an altitude of seven to 10 miles is the *tropos-*

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Looking Ahead in CQ VHF Ham Radio Above 50 MHz

Here are some of the articles that we're working on for upcoming issues of *CQ VHF:*

- Part 2 of "The Magic of Radio Wave Propagation," by Lew Ozimek, N2OZ
- "Make Your HT Talk Forever," by Ken Collier, KO6UX
- "Are NiMH Batteries Really Better?" also by KO6UX
- "The 550T+ Laser Team," by Eric Stroud, KB2TCQ

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- "Two-Meter Mountaintopping with Mirrors," by Edward Butler, KF6DXX
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phere. Temperatures in this layer decrease rapidly with altitude and convection is very active. This is where clouds form and virtually all of our weather originates. The troposphere is an important player in long-range VHF radio communication (we'll discuss that in Part 2 of this article).

The next portion of the atmosphere, located seven to 30 miles from Earth, is called the *stratosphere.* In the *stratosphere,* the ambient temperatures do not change very much with altitude and clouds of water are very rare. The stratosphere does not play a significant role in radio communication.

The *ionosphere* is the next layer out, beginning about 25 miles up and extending 300 miles or more. Of all the gaseous layers, the ionosphere exerts the maximum influence on radio waves because it contains electrically charged, or *ionized*, particles which are capable of deflecting radio waves. The extent of deflection depends upon the intensity of ionization which, in turn, is determined by solar activity.

Within the *ionosphere* are a number of layers, each of which varies in height and extent of ionization based on the time of day, the season, and the intensity of solar activity. The four layers involved in radio communication are depicted in Figure 2.

The closest region to the Earth, the D-*Layer*, sits at 35 to 60 miles of altitude. Its existence is highly dependent upon ionization and, as a result, it disappears at night when the sun no longer shines on it. It is ineffective in bending HF signals back to Earth and its major action is the absorption of radio waves.

The next region, the E-*Layer,* is located 60 to 90 miles from Earth and is characterized by short-lived ionization. It will *refract* radio waves during sunlight hours (that is, when it is ionized), creating a "skip" range of about 1,400 miles on one hop, and multiple hops are possible.

The last two layers of the four are the F_1 and F_2 layers. Layer F_1 is located 80 to 130 miles up and does not significantly affect the range of communications. It is similar to the *D* layer in its ability to absorb radio energy. Layer F_2 is about 150 to 300 miles up and is the most important element in long-range shortwave communication because of its ability to *deflect* radio waves. It creates a maximum "skip" of 2,500 miles in one jump. At night, the F_2 and F_1 layers combine into a single, larger layer which retains the characteristics of the F_2 layer.

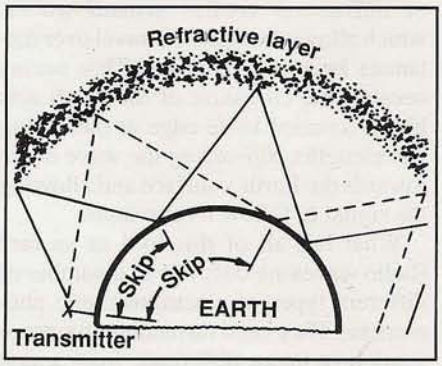

Figure 3. Skywave propagation is the most common means of making long-distance contacts on the HF and low VHF bands. Signals head toward space until hitting a refractive layer that bends them back toward the Earth. The lower the angle of transmission, the greater the distance covered in any one hop, and multiple hops are possible.

So there we have the obstacles to a radio wave's attempt to travel in a straight line, the four gaseous layers which make up our atmosphere. It is hard to consider layers of gas as being destructive or as obstacles, but that is exactly their role. On the other hand, it's only because of these obstacles that our radio signals don't all get lost in space. When conditions are right, one or more of these layers, or combinations thereof, will *reflect* or *refract* radio waves back to Earth.

The point at which reflected waves arrive on the Earth's surface is determined by such factors as the layer(s) involved, the extent of ionization which exists, and the angle at which the transmitted signal strikes the layer. The greater the angle of *reflection*, the greater the distance the waves will travel before returning to Earth. The distance between the point of transmission and the point of return is referred to as the *skip distance* or *skip zone.*

Multiple skips can cover different distances simultaneously as illustrated in Figure 3. Don't be fooled by the illustration into thinking that the areas between "touchdown" points are completely devoid of radio signals. This is far from accurate because an effect called *scatter* diverts signals *into* the skip zone, as well as into other areas. However, any such scattered signals will, as a rule, be weak and somewhat distorted. More later on this and related concepts.

Don't Slam the Door!

Most references to long distance contacts will connect the *sky wave* and *HF*

together. It perhaps is a little glib to say that *sky wave* applies only to HF (that is, to the 3- to 30-MHz bands), implying that no use for it exists on VHF and UHF. In my mind, no door exists in the ionosphere which slams shut when 10 meters is reached, preventing any higher frequencies (or smaller wavelengths) from being *reflected* or *refracted*. In lieu of a rude rejection, such as a slamming door, the only reasonable assumption is that no sharp cut-off exists and that a gradual degradation of performance occurs as frequencies increase. Think of the action as interrelated overlapping effects, or as a gradually changing gradient. Many factors contribute to the final result, including the elevation angle of radiation and the location (surrounding terrain) of the transmitter. Figure 3 also shows how skip range can increase as the transmission angles decrease, thereby increasing reflection angles.

The concept of *maximum usable frequency* or *MUF* may help in understanding the way that changes occur. The highest frequency at which a *vertically incident* signal will be *refracted* (or diverted) by the ionosphere is known as the *critical frequency*. As the angle of transmission is moved away from the vertical, the frequency which will exhibit *refraction* from the *ionosphere* back to Earth increases above the critical frequency. In its simplest concept, *MUF* is the highest frequency permitting communication between two stations *for a specific path*. The maximum one-hop distance for the *E* layer is approximately 1,400 miles, and for the F_2 layer, about 2,500 miles. Published predictions of *MUF* normally are based on median values of transmission paths. *The New Shortwave Propagation Handbook* (see "Resources") will provide you with more data on this topic.

"Of all the gaseous layers, the ionosphere exerts the maximum influence on radio waves because it contains electrically charged, or* ionized, *particles which are capable of deflecting radio waves."

Wandering Waves

With these errant radio waves filling our atmosphere, a varying pattern of *refraction, diffraction, reflection*, and *scattering* is constantly taking place in different combinations. These actions are tied rather specifically to the atmospheric layer(s) involved, as well as the frequency employed. To understand the true propagation characteristics of the *ionosphere*, however, and the differences which occur between HF and VHF/UHF signals, we must look at each layer independently and identify the special communication modes which can occur. These aspects will be covered in Part 2 of this article. ■

Resources

For more detailed information on propagation basics, we recommend *The New Shortwave Propagation Handbook*. by G. Jacobs, W3ASK; T.J. Cohen, N4XX; and T. Rose, K6GKU, published by CQ Communications, Inc., 25 Newbridge Rd., Hicksville, NY 11801; Phone: (516) 681-2922; Fax: (516) 681-2926.

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The Magic of Radio Wave Propagation—Part 2

We continue our propagation primer with a close-up look at the ionosphere and at VHF/UHF propagation modes.

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Part 1 reviewed the discoveries that led to our current understanding of the "science" of radio wave propagation. It defined the concept of critical frequency and the way the atmosphere affects radio waves via refraction, diffraction, reflection, and scattering. The four layers which make up the atmosphere were defined and their general role in radio wave movement was introduced. In Part 2, we'll cover the specific propagation characteristics of the ionosphere, with special emphasis on VHF/UHF signals and some of the special communication modes applicable on these higher frequency bands.

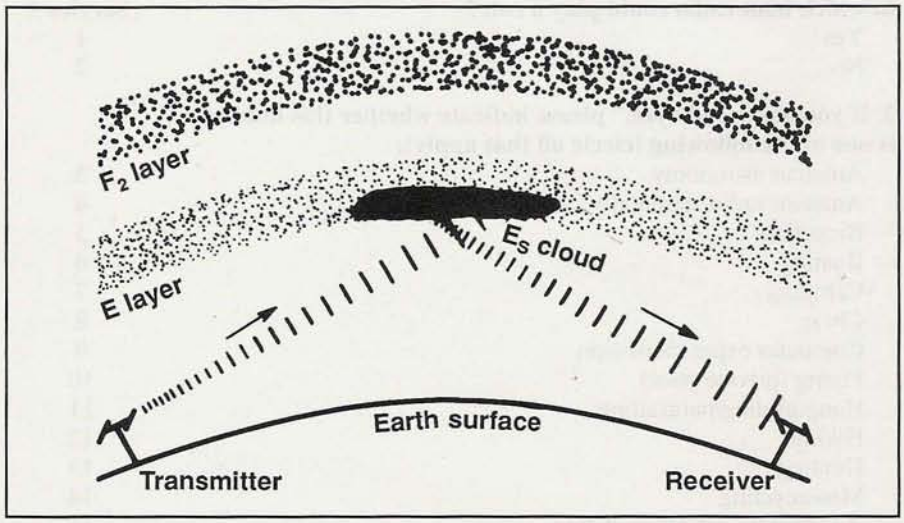

*Figure 1. Sporadic-*E*, or* E_s*, reflections occurs when a VHF signal which would normally travel on a straight line through the* E *and* F_2 *layers of the ionosphere hit a highly ionized* E_s *"cloud," which reflects the signal back to Earth. These clouds may move around, and generally last no more than a few hours.*

The four atmospheric regions which control all radio signals traveling via skywave are the *D*, *E*, F_1, and F_2 layers of the ionosphere (see Part 1 for basic definitions). *D* and F_1 are normally of limited value in *reflecting* or *refracting* radio waves; they usually only absorb signals, except as described below. *E* and F_2 are the true heavyweights in the communication arena, accounting for the bulk of long-range contacts, especially in the HF (high frequency) range. But as most of us know, whenever a rule exists, it's quite common to find exceptions. Such exceptions in radio propagation, however, can open exciting possibilities for VHF/UHF fans.

The D Layer—An RF Sponge

The *D* layer becomes ionized during daylight hours and acts as a giant sponge, absorbing radio energy. The extent of absorption is directly related to the intensity of ionization. Under typical daylight conditions the *D* layer is capable of severely curtailing effective transmission of signals at 1.8 MHz (160 meters) and 3.5 MHz (80 meters). As the frequency increases into and above the 40-meter band, it becomes easier for radio waves to pass through the *D* layer, despite the extent of its ionization. But as long as the *D* layer is ionized, some absorption takes place and the signal strength is attenuated.

At night, the *D* layer ionization drops dramatically, permitting lower frequency signals to pass through to the *E* and *F* layers. When *D* ionization drops sufficiently, the *MUF* (*maximum usable frequency*, see Part 1) will usually rise to a point high enough to achieve good long-distance performance on the 1.8- and 3.5-MHz bands. The ability of 7- and 10-MHz signals to travel long distances also improves because of the reduced absorption in the *D* layer, permitting low-angle waves to reach the *F* layer. This change in the *D* layer at night sometimes permits AM broadcast signals to be received over very long distances.

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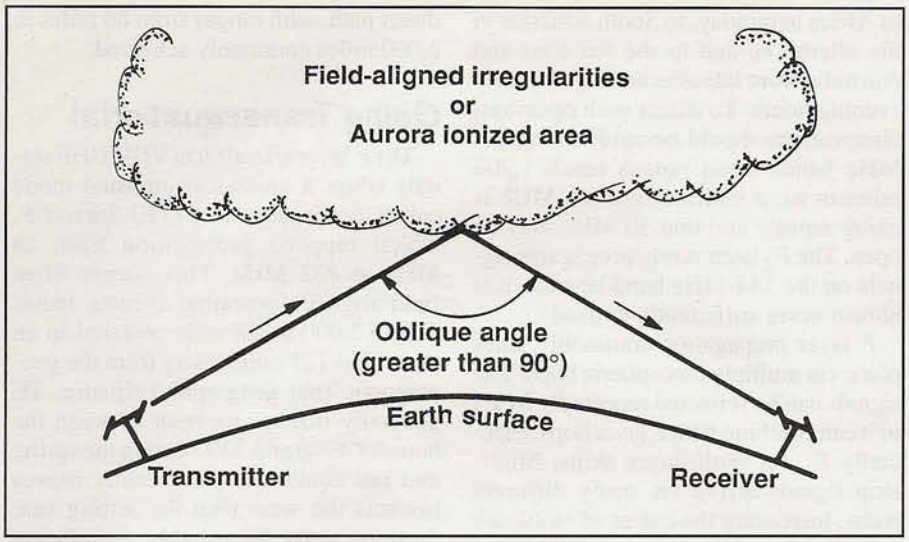

Figure 2. Example of an oblique path between two stations. The refracting medium (in this case, a field-aligned or aurora-ionized area; see text) bends the signal at an oblique angle, that is, greater than 90 degrees. The larger the angle, the greater the distance between the two stations.

The makeup of the *D* layer can be characterized as having *irregularities* which are important to VHF/UHF. These special conditions may permit propagation of radio signals in the 25- to 225-MHz range by *scattering*. Such propagation, called *ionospheric forward scatter*, includes high losses which result in weak, fluttery signals. *Ionospheric forward scatter* is best when the sun is highest (1000 to 1400 local time) and worst at night. Maximum path length is approximately 1,200 miles with signals near the noise level, mandating the use of a sensitive receiver, a good antenna such as a three-element Yagi (as a minimum), and several hundred watts of power. CW is the best mode, but SSB is possible.

"Skipping" to E

Like the *D* layer, the *E* layer essentially exists only in the daytime. But unlike *D*, it has a critical frequency of about 3.5 MHz, and it provides useful *diffraction* of signals between 5 and 20 MHz to allow ranges of up to 1,400 miles. However, the extent of *absorption* by the *D* layer dictates what ranges can be achieved by *E* diffraction (lower radiation angles mean longer time of passage through the *D* layer with more absorption of energy). High-angle signals pass through the *D* layer quickly and lose less energy, but since the high angles of penetration result in lower angles of reflection, the effective *E* layer skip is limited to about 750 miles. Nonetheless, the *E* layer is a major player in VHF/UHF propagation, producing several important propagation modes.

Sporadic-E, or E_s, reflections occur because of unusually dense patches or *clouds* of ionization which develop in the *E* layer (see Figure 1). These clouds normally form quickly, move about suddenly, and last for only a few hours. When they're present, they can produce long-range communication at frequencies up through 144 MHz (with at least one confirmed opening on 222 MHz).

Sporadic-*E* occurs most commonly in the northern hemisphere during May, June, and July, with a lesser season occurring in late December and early January. Openings usually develop between 0900 and 1200 and 1700 and 2000 local time, but there are plenty of exceptions during peak periods. The exact causes of E_s are not yet fully understood. It is independent of the solar cycle, though, so the ionization involved must come from other factors, such as wind shear or meteoric metal ions.

Since E_s is short-lived, the operator must be alert to detect it. When the skip on 28 MHz (10 meters) drops to about 250 to 300 miles, it's an indication that the MUF probably has reached 50 MHz (6 meters) for low-angle radiation, an alert that the 6-meter band is most likely wide open (*monitoring 6-meter beacons is also a good indicator of band openings—ed.*). Then, when the skip on 6 meters drops to about 400 miles, the MUF probably has reached 144 MHz (2 meters), permitting long-range contacts there. When these conditions occur, following E_s up the ladder can be fun. One interesting aspect of E_s is that reflections from the F_2 layer are sometimes reflected up by E_s to be re-reflected down by F_2 to achieve even greater ranges.

Another special form of *E* propagation is *E*-layer *FAI (field-aligned irregularities)*. Sometimes after an E_s event, electrons associated with that event become aligned vertically along magnetic field lines. When this occurs, long-range contacts may be made on 50 and 144 MHz because of "oblique" scattering. The oblique effect occurs when radio waves strike the field-aligned electrons and are reflected obliquely (at an angle greater than 90 degrees). The greater the angle of reflection, the greater the range covered. This effect is depicted in Figure 2.

The best time for this to occur is between the hours of 2000 and 2400. FAI signals are weak and fluttery, like those associated with *aurora*, or *Au* (described later). The best way to be successful is by pointing the antenna at an area that represents a recent E_s reflection point. One hundred watts and a single Yagi can be effective. Contacts have been made in this way on 50 and 144 MHz and are also possible on 222 MHz. Sometimes, FAI appears on 2 meters even if the E_s opening involved only produced long-range contacts on 6 meters.

Meteor Scatter

Meteor Scatter or M_s is another special mode for VHF/UHF. The Earth's atmosphere is bombarded every day by billions of meteors. Don't get concerned that the sky's falling; we're not talking about chunks of space debris the size of the ones that created Meteor Crater in Arizona many years ago or that destroyed the forest area of Siberia in 1908. The meteors we're talking about are tiny specks the size of dust particles or grains of sand that burn up as they enter the atmosphere. At night, these "shooting stars" can be seen during a burning period which lasts anywhere from one second to a minute or so.

An ionized trail 5 to ten miles long follows and exists as long as the burn lasts. These ionized "tails" are capable of refracting VHF signals at frequencies up to 440 MHz. The best reflections occur if the meteor is broadside to the transmitted wave, and the most effective frequencies are usually under 100 MHz

because reflected signal strength drops sharply when the frequency exceeds 100 MHz. The short duration of the ionized stream makes contacts fleeting at best, often necessitating prearranged schedules in order to be successful. Although meteors fall at all times, there are five major annual meteor showers which provide good opportunities for contacts—along with the best chances for random (non-scheduled) contacts (see Table 1). For more details on the phenomenon, see References 2 and 3.

Aiming for an "F"

F layer propagation, which was introduced in Part 1, is the most important factor in the ability of the atmosphere to affect communications. The *F* layer consists of two major elements: F_1 and F_2

The F_1 layer exists only during daylight hours. Signals below 10 MHz (30 meters) rarely reach the F_1 layer because they are *absorbed* by the *D* layer or refracted by the *E* layer. Signals above 20 MHz (15 meters and up) usually pass through the F_1 layer without much difficulty and go on to the F_2 layer. The refraction which sometimes takes place in F_1 during the summer in the 10- to 20-MHz range cannot be distinguished from F_2 refraction.

The F_2 layer persists during the day as a distinct layer, but at night it absorbs the F_1 layer to make a single larger layer. F_2 ionization varies considerably at different times of the day, different seasons, and different points in the sunspot cycle, but it's never completely absent. As the ultraviolet radiation from the sun increases, the MUF of F_2 likewise increases. It builds rapidly starting at sunrise, reaches its peak in early afternoon, and decreases quickly to sunset. *It is the most important factor for long-distance HF communications*. In contrast to other layers, daytime ionization of F_2 is four times greater in the winter than in the summer. This occurrence makes the winter MUF superior to the summer.

Regular F_2 layer openings generally occur at frequencies up to about 30 MHz, but openings are possible on 50 MHz, or even higher, during peak years of each sunspot cycle. Such openings peak during the winter in the direction of the Far East and Europe. For the balance of the year, contacts will mainly be to Africa, South America, and the Australasia region. They are generally daytime events with openings to Europe in the morning, to Africa at midday, to South America in the afternoon, and to the Far East and Australia from late afternoon to the early evening hours. To detect such openings, observations should be made in the 28-MHz band; when ranges reach 1,200 miles or so, it indicates that the MUF is rising rapidly and that 50 MHz may be open. The F_2 layer rarely propagates signals on the 144-MHz band because it is almost never sufficiently ionized.

F layer propagation commonly takes place via multiple ionospheric hops. The signals can be reflected repeatedly by F_2 or it can combine with *E* layer hops, especially E_s, for multi-layer skips. Multiskip signals arrive via many different paths, increasing the extent of *multipath* fading. Most HF contacts follow the shortest *great-circle* path between stations. But sometimes, the opposite route can be employed to provide stronger signals with less fading. This is called *long-path propagation.*

A special form of long-path propagation is *gray line*. At the end of a day, the *D* and *E* layers quickly disappear whereas the *F*-layer MUF declines more slowly. This establishes a special condition which permits contacts on lower frequencies (such as 1.8 and 3.5 MHz) during the period of time between the disappearance of *D/E* layers and the complete decline of *F*. This condition can last for 30 minutes to an hour during sunset, with an equivalent condition occurring at sunrise.

F layers can also scatter signals within the skip zone, producing contacts not possible in any other manner. Such signals are seen just above the MUF for the direct path, with ranges from 60 miles to 2,000 miles commonly achieved.

Going Transequatorial

The *F* layer also affects VHF/UHF signals when it creates an unusual mode called *Transequatorial (TE) Spread F*, which supports propagation from 28 MHz to 432 MHz. This occurs when field-aligned ionization creates bands 300 to 2,000 miles wide centered in an area 65 to 125 miles away from the geomagnetic (*not* geographic) equator. TE generally reaches its peak between the hours of 1700 and 2200 during the spring and fall equinoxes. It normally moves towards the west with the setting sun. Stations must be roughly equidistant from the magnetic equator to make contact, and both high power and large antennas are normally required. It's possible to reach ranges of 5,000 miles in this mode.

Non-Ionospheric Propagation

Tropospheric Propagation

The *troposphere* also provides unique VHF/UHF communication propagation modes. The troposphere was defined earlier as the region which extends from seven to 10 miles above the Earth's surface. The layer has very little impact below 30 MHz (10 meters), but it's very important at frequencies above 50 MHz. *Tropospheric propagation*, or *tropo*, results from weather conditions only and is not affected by solar conditions or geomagnetic activity. The specific tropos-

Table 1

Name	Peak Dates	Meteors/Hour (approx.)
Quadrantids	Jan. 3–4	50
Arietids	June 7–8	60
Perseids	Aug. 11–13	75
Orionids	Oct. 20–21	20
Leonids	Nov. 17–18	25*
Geminids	Dec. 11–13	60

*The Leonids are not included on most lists of major showers, but a "meteor storm" is expected from this shower for 1998 and/or 1999.

Table 1. Major annual meteor showers by dates of peak activity and intensity.

Table 2

Propagation Mode	N.A. Distance Record (miles)	
	144 MHz	222 MHz
Aurora (Au)	1347	1298
Meteor Scatter (MS)	1960	1274
Transequatorial (TE)	3933	3670
Tropo (Continental)	1687	1275
Tropo (Pacific)	2574	2574

Table 2. Range performance comparison between 144 MHz (2 meters) and 222 MHz (1.25 meters), using North American distance records for various propagation modes (as of July, 1998). As you can see, 222 MHz provides similar propagation to 2 meters, although generally over somewhat shorter paths. Data courtesy Al Ward, W5LUA.

pheric propagation modes available to VHF/UHF enthusiasts are quite varied and include the following:

Troposcatter—Most VHF-plus communications are line of sight. The line of sight distance to the horizon of an antenna at 100 feet is about 15 miles. But, under average conditions, radio waves are refracted toward Earth, generally making the radio wave horizon 15 to 20% longer than the visual horizon. Tropospheric refraction will increase the radio wave horizon significantly. However, VHF contacts are made every day at ranges of 50 to 300 miles without any obvious propagation help. Contacts of this nature are called troposcatter, which is a form of scattering in the troposphere. It's caused by temperature and humidity changes, by water vapor, by atmospheric turbulence, or by clouds or dust in the area. No special equipment or procedure is required to use troposcatter, but the maximum range increases significantly with increased antenna height.

Raindrops are quite capable of providing a troposcatter condition known as *rain scatter* at frequencies from 1296 MHz to 10 GHz. The drops of water are large enough in relation to the wavelength of the signals at these frequencies to scatter the radio energy, permitting contacts over the horizon even at low power. Rain scatter on the microwave bands can produce contacts as far away as 120 miles.

Tropospheric Refraction—Changes in temperature, atmospheric pressure, and humidity will change the "index of refraction" of air, which controls the extent of refraction of radio waves. Higher levels of refraction increase the range of VHF and UHF signals by up to several hundred miles. The higher the frequency, the more sensitive it is to refraction, thus microwave transmissions may show these effects before they are seen at lower frequencies.

Tropospheric Temperature Inversion Ducting—This is also known more simply as *tropospheric ducting*. In the troposphere, temperatures normally decrease rapidly with altitude. But if a *temperature inversion* condition develops, the temperatures about one to three miles above Earth will be *higher* than the temperatures closer to Earth. This temperature difference creates boundary lines or *ducts* which are capable of guiding VHF/UHF radio waves over relatively long distances.

I remember being on the bridge of a U.S. Navy destroyer in the waters near Cuba and hearing a voice transmission on VHF from a sister ship which was in Virginia at the time. In all probability, this was some form of tropospheric ducting. There's a regular duct that develops each year between Hawaii and the west coast of the continental U.S., allowing VHF and UHF contacts with the simplest equipment—as long as both stations are "in the duct."

Aurora

Aurora displays are quite common in the northern and southern magnetic pole regions. They're a beautiful sight to behold and consist essentially of ionized layers of atoms and molecules of gas. In the northern hemisphere, they develop in an *auroral oval* that can spread across

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Alaska, Canada, Greenland, Iceland, Scandinavia, and Russia. They occur at *E*-layer heights and can be quite disruptive to shortwave communication by absorbing signals and creating flutter. In the 6- and 2-meter bands, however, it is quite common to have *aurora reflections* and *aurora*-E openings which provide outstanding long-range communication. *Auroral ionization* is similar to field-aligned ionization, and it will show many of the characteristics of FAI discussed earlier. Au openings can occur during the day or at night and are generally of short duration. Ranges of 1,200 miles can be achieved by these modes. Auroral contacts are possible even from locations where the aurora is not visible, such as the Au contacts made last summer from Georgia and Florida.

The Longest DX

It's possible for two stations which can simultaneously see the moon to communicate with each other by bouncing VHF or UHF signals off the moon's surface. This is called *Earth-Moon-Earth* communication, or *EME*. Because of the distances involved, path losses are extremely high. In addition, the irregular surface of the moon does not provide an efficient reflective surface, further reducing the signal strength available at the receiving station. As a result, high-gain antennas and high power are required to be successful (*although there has been one single-Yagi-to-single-Yagi EME contact on 2 meters—ed.*). Stations which use this mode can be as much as 11,000 miles apart and still be successful. Now *that* is long range communication!

A Band-by-Band Review

Let me step back, if I may, to summarize, band-by-band, the propagation factors which affect VHF and UHF frequencies, including the 10-meter band (which often acts like a VHF band), with an indication of the level of performance which may be achieved.

28–30 MHz (10 meters)—A transitional band between HF and VHF, it's highly dependent upon solar activity and the resultant long distance F_2 propagation. Normally, communication is open from sunrise to just past sunset, but can be open much later in the day during sunspot peaks. Sporadic-*E* is very common during the spring and summer months. This is the lowest frequency at which contacts can be made using *meteor scatter* (*MS*), Au, auroral-*E, and* Transequatorial Spread *F* modes.

50–54 MHz (6 meters)—Using this band, amateurs can operate regularly via tropospheric scatter and achieve ranges of 200 miles or more. During sunspot cycle peaks, long-range DX contacts can be made during daylight via the F_2 layer, where F_2 *back-scatter* and TE are also very effective. Sporadic-*E* is quite common, achieving single-hop ranges up to 1,400 miles during spring and summer. *Multiple-hop* E-*skip* occurs in the summer as well. Other modes which are possible include FAI, Au, and auroral-*E* propagation as well as meteor scatter.

144–148 MHz (2 meters)—This band offers effective *F* layer propagation only in the TE mode. Sporadic-*E*, and multiple-hop sporadic-*E* occur, but rarely. Aurora propagation similar to that which occurs on 6 meters is possible, but with signals which are weaker and more distorted. Meteor scatter contacts on these frequencies are most common during the annual meteor showers. However, 2-meter MS contacts are possible at virtually any time using the *High-Speed CW* (HSCW) techniques outlined in the September, 1998, issue of *CQ VHF* (see Reference 3). Tropospheric propagation in all of its forms is very important at these frequencies with tropospheric ducting being the most effective with ranges of 1,200 miles over land and 2,500 miles over water.

222–225 MHz (125 centimeters)—This has performance characteristics almost the same as the 2-meter band. A comparison of peak performances on both bands is shown in Table 2. Note the similarity in maximum ranges achieved. The best special modes are those related to tropospheric effects.

420–450 MHz (70 centimeters)—This band has demonstrated long-range communication capability for Au, MS, and tropospheric propagation modes, especially tropo ducting.

902–928 MHz (33 centimeters)—This offers long-range contacts primarily under Au and tropospheric modes, along with EME.

1240–1300 MHz (23 centimeters)—This shows long-range capability normally only under tropospheric conditions and EME.

For all of the microwave bands, amateurs have successfully made contacts by relying on *knife-edge diffraction* and rain scatter, and there have been EME contacts on several microwave bands. The most effective modes, however, seem to be those related to tropospheric conditions.

A Grand and Wondrous Thing

By now, I am sure that everyone will agree that the umbrella surrounding the Earth called the atmosphere is a grand and wondrous thing. The special geomagnetic conditions of the atmosphere, the characteristics of radio waves, and the dependence of such waves on sunspot activity for effectiveness, combine to form a complex and confusing set of concepts. However, these must be at least partially understood if we are to try to use them to improve communication during the current increasing solar cycle. Knowing what to look for and what to try is the first step in expanding our horizons, both figuratively and literally.

The review of the various VHF/UHF modes pointed out that the world of such frequencies is a far more challenging communication problem than HF. Perhaps that's why so many people concentrate on these bands and why they achieve so much pleasure from success.

I hope that your interest has been somewhat piqued by this article and that you pursue the unique communication possibilities covered. Your ultimate achievement may be making special types of contacts, using new modes, or, perhaps, reaching distances far beyond anything you may have imagined in the past. Good luck and good DX. ■

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